CHAPTER 38

Economics of Ergonomics*

Tapas K. Ray, Thomas R. Waters, and Steve Hudock

CONTENTS

38.1 INTRODUCTION

Ergonomics is the science of designing safe and productive workplaces and jobs for workers. Studies have shown that workers whose jobs are physically demanding or are poorly designed from an ergonomics perspective are at significantly increased risk of developing work-related musculoskeletal disorders (WMSDs), such as low-back pain (LBP) and distal upper-extremity musculoskeletal disorders (MSDs) (NIOSH 1997; NRC and IOM 2001).

* The findings and conclusions in this chapter are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

Workers in these high-risk jobs also have significantly more lost workdays (LWDs) than those whose jobs are considered to be ergonomically designed. Studies have shown that WMSDs and the associated reductions in productivity account for significant financial costs for companies.

If an existing job or workplace is thought to be of poor ergonomic design, then some type of ergonomic solution or intervention is needed to decrease the risk to the worker. The interventions typically include "retrofitting" or modifying the job or workplace and can involve either significant changes (such as in work processes) or simple changes (such as in layout of the workstation). Jobs that are still in the conceptual phase can benefit from ergonomic assessment, by which they are critically evaluated and designed from an ergonomic perspective before workers actually perform them. This approach is sometimes referred to as *design in ergonomics* or *prevention through design*. The cost of ergonomically designing a safe job is reportedly more than one-tenth that of retrofitting the job after a problem has been discovered.*

From an employer's perspective, it is important to consider how the design of the work, its processes, and the work site affect the financial success of the business. Rapidly changing economic conditions have a profound effect on a firm's decision-making as well. The safety manager, industrial hygienist, managers, and executive officers will base occupational-safety investment decisions on employee health, risk management, and the financial consequences of those investments. Decisions to implement ergonomic interventions may be driven either by the benefits of maintaining a healthy and safe workforce or by their contributions toward productivity and business profits. In either case, however, it is necessary to calculate the costs and benefits—in terms of health or money—resulting from such actions.

This chapter gives readers insight into the types of economic evaluations that can be performed and how they can be used to assist in making decisions about implementing specific ergonomic interventions. We first briefly introduce the principles of economics and ergonomics and their underlying philosophies. We then describe current types of economic analyses and provide simple examples of their application in real-world situations. The chapter also lays out the steps of an economic analysis, briefly discusses ergonomic intervention approaches, and introduces a host of available tools commonly used for cost-benefit analysis (CBA) of ergonomic interventions. To broaden the scope of this chapter, we discuss decision-making in the face of uncertainty, health-valuation approaches, and intervention-evaluation examples. The goal is to assist readers in subjective and objective valuation of ergonomic practices.

38.2 PRINCIPLES OF ECONOMICS

Resources such as land, labor, capital, and time are scarce. The goal of economics is to study how efficiently these resources can be allocated to maximize the welfare of respective economic agents.† For this chapter the term economic agent will imply the following: (1) the firm's owner, manager, employer, and share holders; (2) the employee, worker,

* This has been opined by Mr. D. Alexander, PE, CPE, in his address to National Advisory Committee on Ergonomics (NACE) meeting in 2004. Refer to http://www.osha.gov/SLTC/ergonomics/nace_mins_1_2004.html

† See Samuelson and Nordhaus (2001).

union member, safety engineer, manager, and industrial hygienist; and (3) the family members of the workers, insurers, health care workers, neighbors, regulators, and the government. Similarly, resources will imply the firm's capital, budget appropriated for workplace safety, business reputation and morals; workers' mental and physical health, work time, and leisure time. Efficient allocation of resources, within and outside a workplace, can be achieved only with consideration of the true costs and benefits associated with maintaining (1) worker safety and health, (2) high worker productivity, and (3) high product quality.

Identifying the principle economic agents involved and the resources to be analyzed is of primary concern and constitute important building blocks of any economic analysis of occupational safety and health (OSH). Oftentimes, managements need to be convinced that a recommended ergonomic solution is cost-effective (CE) before authorizing expenditures to implement the solution. To prove that an ergonomic implementation will be CE, an economic analysis must show that the benefits outweigh the costs. If the economic analysis is not properly conducted, it may fail to convince management and other related stakeholders and may deter the workplace and the society from reaping the true benefits (both in health and monetary terms) of ergonomic interventions. This will lead to misallocation of vital resources such as labor and capital.

38.3 PRINCIPLES OF ERGONOMICS

The primary goal of ergonomic design is to ensure that work processes and tasks are within the safe physical capabilities of the workers. This means that the required forces and weights required to perform the job should be kept sufficiently low so as to not exceed workers' strength or mechanical tolerance limits of their musculoskeletal tissue. It also means that the frequency of the task should be kept sufficiently low so that the work does not induce repeated mechanical insult to the musculoskeletal tissues or induce unhealthy physiological responses that can lead to cumulative trauma disorders (CTDs). In addition, the work should be designed so that the required posture of a worker's trunk and limbs is maintained in as near neutral position as possible (i.e., extreme or awkward postures are avoided) during the work processes. Postural stress can lead to increased risk of developing WMSDs, just as static body positions (those that must be held for more than a few minutes at a time) can increase the risk of local muscle fatigue and injury, as well as ligament strain.

When work is poorly designed from an ergonomics perspective, often some type of intervention is implemented to reduce employees' exposure to the risk factors. This may involve a number of different approaches, such as changing the design or layout of the workstation, adding assistive equipment or technology, adding workers or rotating workers to reduce exposures, and modifying the work itself. These approaches almost always have associated costs, which must be considered in choosing the best solution for a specific job.

38.4 ECONOMICS AND ERGONOMICS AND THEIR COMMON GOALS

As noted previously, the goal of ergonomics is to design safe and productive jobs and workplaces to protect workers from injury and illness. Similarly, one of the goals of economics is efficient allocation of resources. Clearly these goals are in alignment because safe and productive work environment not only protects workers but controls wastage of resources such as compensation expenses, lost time and effort, and workers' morale and health. Appropriate allocation of these vital resources also leads to productive efficiency by encouraging more output with fewer resources and at a lower cost. The problem is that it is not always easy to determine the payback that may result from implementation of an ergonomic intervention. The benefits of such a program are in terms of reduced future injuries, illnesses, and increased potential output, results which might not have occurred otherwise and thus are seldom visible. Properly designed economic modeling can incorporate such uncertainties and may estimate expected program benefits. It will also predict how long it will take for interventions to provide a return on the investment (ROI). Often, employers ask, "Will this intervention pay for itself, or will it just cost us a lot of money?" Management will be more likely to embrace interventions if they result in efficient utilization of the company's critical resources, namely, money and employees' time. In fact, an intervention may bring forth a positive change in the relationship between resources (labor and capital) and outcome (production output). Consider Figure 38.1. The bold curve, commonly known as a production function,* relates labor with output for specific capital inputs. Any point on the curve signals production efficiency. However, poor ergonomics may prevent the firm from reaching point A and force it down to point A′, thereby losing output A–A′ in the production process. A properly redesigned ergonomic workstation not only helps in attaining point A but also may generate a new production frontier by alternating the existing relationship between labor and output, shown by the dotted line in the picture. The investment may lead the firm to produce at point B. Most decision-makers focus on A–A′ while deciding to intervene or not. A properly designed economic study should focus on B–A′ in order to predict the real returns on investment.

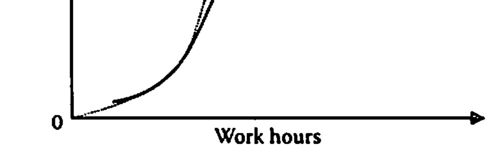


FIGURE 38.1 Production frontier and unrealized gains from intervention.

* A production function is a function that specifies the output of a firm, an industry, or an entire economy for all combinations of inputs. It is generally believed that Philip Wicksteed (1894) was the first economist to algebraically formulate the relationship between outputs and inputs as $P = f(x_1, x_2, \ldots, x_m)$, although there are some evidences suggesting that Johann von Thünen first formulated it in the 1840s. See Humphrey (1997).

Seabury et al. (2005) sum it up in this way: "If poor health makes the worker less productive and if employers are unable to replace unhealthy workers with healthy ones at no cost (or unhealthy trained workers with healthy untrained workers), then employers will also obtain some benefit from reducing poor health among workers."

38.5 TYPES OF ECONOMIC ANALYSES

Economic evaluation of ergonomic interventions can be defined as applying analytic methods to *identify*, *measure*, *value*, and *compare* the costs and consequences of alternative prevention strategies. The purpose of economic evaluation is to replace ad hoc decision-making with informed decision-making. Every decision regarding ergonomic intervention—be it primary, secondary, or tertiary—is associated with an opportunity cost. Decisions backed by economic evaluation help in reducing those costs. The three broad categories of economic evaluation of ergonomic hazards are (1) evaluating the economic burden of the hazard or exposure to that hazard, (2) measuring effectiveness of hazard controls or preventive interventions, and (3) comparing alternative preventive strategies to help choose the optimal one. The corresponding economic analyses are cost analysis (CA), cost-benefit analysis (CBA), and cost-effectiveness analysis (CEA).

38.5.1 Cost Analysis: Costs Associated with Poor Ergonomics

CA is a form of *economic evaluation* that involves the systematic collection, categorization, and analysis of data on the costs associated with poor ergonomic design of work or a workplace and the losses due to associated injuries and illness.* Oftentimes, injuries or illnesses are the end results of cumulative problems that have already been costly in terms of presenteeism† and increased absenteeism.‡ The economic burden to the workers, their families, and society in terms of endangered health and reduced household production might be significant even without injuries and illnesses; therefore, tracking numbers of injuries or illnesses may not reveal the already diminishing productivity§ due to declining labor health. Cumulative exposures to physical stressors may take time to manifest; however CA can be used as a problem identification process. Exposure assessment and CA can estimate production loss. Even when the number of injuries or illnesses is known, the associated costs and business impact may not be fully realized or estimated. CA can be used to reveal those losses to the company. Costs are measured in terms of *opportunity costs*—the output that could have been achieved if the resources had been properly used. Ergonomic-related injuries and illnesses will lead to deficient outcomes such as worker-health impairment; lost work time due to workers' non-comfort, illness, or injury; and decreased output due to work stoppage. In turn, these factors may lead to increased employer-sponsored or privately sponsored medical expenses and disability adjustments, reduced employee morale, pain and suffering of workers and their

* Cost of injury and/or illness hereafter signifies costs related to occupational injuries and illnesses.
† Presenteeism occurs when workers are present at work but are less than 100% efficient.
‡ Absenteeism occurs when workers are absent from work because of health conditions.
§ Productivity in simple terms is measured as output over input.

families, and negative social externalities. A true assessment of these costs will trigger intervention-seeking behavior by decision-makers. Traditionally, these costs are broadly categorized as direct or indirect:

1. Direct costs include the medical expenses associated with injuries and illnesses. Often this is combined with insurance administration costs* (the overhead for running an insurance company). For disabling injuries and illnesses, medical costs include worker compensation (WC) and immediate and long-term medical expenses associated with occupational injury or illness, as well as loss of income if an employee is not able to return to work, such as with disability (Leigh et al. 2004):

$$\text{Direct cost} = \text{medical expenses} + \text{insurance administration cost}$$

   A majority of injuries and illnesses, although originating from the workplace, may not result in WC claims, and the associated medical expenses may differ from those in WC cases. The average cost of a WMSD case that is not reported through WC claims can still be estimated. Leigh et al. (2004) suggests that such costs can be estimated by multiplying WC claim costs by 89% (Baker and Krueger 1995).

   Direct costs are visible and hence termed direct. They are associated with mainly injuries and illnesses and may fail to reflect the majority of the costs associated with work hazards due to improper ergonomic designs, especially when the relationship between the hazard exposure and the injuries is not clear or may take time to build.

2. Indirect costs do not include costs covered by WC insurance but are expenses paid out by the company or the worker or the society. Although these are real costs, they are often thought of as hidden because they are not easily tracked or assigned a value and they are often ignored. These indirect costs include such things as absenteeism, presenteeism, hiring replacement workers, training new workers, loss of productivity and quality during the training and learning period, overtime payments, accident investigation, delayed return to work, counseling, and other costs that may be difficult to assess. Indirect injury costs have typically been reported to be two to five times greater than the direct costs. According to Leigh et al. (2004), they constitute 79% of total occupational injury costs, whereas the indirect costs of illnesses (such as Carpal Tunnel Syndrome [CTS]) constitute 34% of total occupational illness costs. Because many companies try to reduce direct costs by reassigning injured workers to modified or light-duty jobs, the cost of this modified work is often ignored or not included in a CBA:

* These are the costs incurred by insurers and are usually measured by the difference in their (insurers') total revenue (premium) and the WC benefit payments. For private insurers, this will include the abnormal profits they earn. See Rice et al. (1989) and Leigh et al. (2004) for further discussion. Leigh et al. (2004) assume administrative costs for WC claims to be 31% of the total medical costs, and Cutler (1994) assumes 15% for non-WC claims.

Indirect costs = lost work time of injured workers (absenteeism)
+ lost efficiency of injured worker while at work (presenteeism)
+ wastage of resources (idle capital and labor due to the absence of injured workers)
+ higher turnover costs (hiring and training)
+ worsened employee morale, resulting in low productivity (output per worker) as well as low quality of service or product
+ personal losses such as household services (social cost component)

Workplace hazard exposures that result in cumulative trauma and injuries/illnesses take time to become acute and to lead to workplace absences. Thus, before the injuries/illnesses get severe enough to be recognized and recorded, they may already have resulted in a significant loss of productivity. Efficiency is affected in the form of presenteeism (production below potential). Measuring presenteeism can be a challenge.

Absenteeism is measured by the numbers of days a worker is absent because of sickness (sick leave) and the resulting loss in potential output, usually estimated by the hourly wage. Most wage estimates are after-tax figures and should be adjusted to before-tax replacement costs. The literature includes various related conversion factors, such as described by Leigh et al. (2004). Further, a wage reflects the contribution of the worker at the margin and fails to reflect any surplus he or she generates. It would theoretically be more appealing to replace wages with the average output generated, assuming zero unemployment. Higher unemployment implies a lower opportunity cost for the replaced worker and at the extreme, costs due to absenteeism could be zero. For example, if the injured worker is unskilled, part-time, and fails to file a WC claim, then his or her absence may not affect the overall output if a replacement worker is readily available.

Absenteeism costs should also include fringe benefits. U.S. Chamber of Commerce (1993) estimated fringe benefits to be 54% of pretax compensation.

Presenteeism is difficult to value monetarily because it depends on the specific production process, intervention, and technical sophistication of the enumerator, data availability, and market condition. A worker may produce at less than optimal capability and are more prone to error, which seldom goes noticed if there is no one-to-one mapping between individuals' working hours and the output generated, if the production function is nonlinear, or if the market constraints are such that working at full potential may generate idle surplus.* Sometimes, employers do not share complete information about the production frontier that is technically efficient.

* Interested readers should look at the classic paper of Alchian and Demsetz (1972) on presence of moral hazard in team production.

Unlike other cost components, the burden of presenteeism is borne by employers alone, and the chances of directly shifting these costs to other parties are remote. Few studies have focused on quantifying the cost of presenteeism. Goetzel et al. (2004) estimated the annual costs at between $22 and $157 per employee. These costs were calculated by determining the number of unproductive hours attributable to presenteeism and multiplying that number by $23.15, the average U.S. wage and benefit in 2001. Similar estimates can be found for several illness conditions in Pauly et al. (2008).

Turnover costs have three main components: (1) staffing (in addition to the recruiting and hiring costs for the initial worker, the organization must spend a similar amount to hire the replacement), (2) vacancy (the period during which an employee is not working results in lost productivity and potentially lost business), and (3) training (employees are not 100% productive from the moment they start working). It is important to understand how much money is spent on these activities.

CA not only highlights the importance of intervention by revealing the true damage caused by ergonomic-related hazards but also may be effective in finding out who bears the burden. The economic burden of poor ergonomics may be borne by the employers in terms of higher costs; by the employees in terms of the detrimental impact on health and wages; by insurance agents in terms of higher compensatory expenses; by the families in terms of suffering and a reduction in assistance from the injured workers; and by society in terms of higher prices, lower output, and less value. The burden may be shifted from one agent to another and then to the society as a whole subject to the market constraints.

In addition to estimating economic burden, CA is used to estimate the costs of intervention. The economic costs of an intervention program (workplace ergonomic redesign) are not just the dollar amount spent on it but also the value derived if the resources had been allocated to their next best use. The cost categories are similar to those outlined previously. The important difference, however, might be reflected in the time period considered. Typically, costs of ergonomic-related illnesses and injuries reflect longer time spans, accounting for the life span of the endangered cohort of workers. Intervention costs, on the other hand, are estimated on the basis of short-term investment and long-term maintenance costs. Although cost categories are intervention-specific, Table 38.1 suggests various intervention cost entries.

CA is an important component of all economic evaluation techniques. Once the costs associated with ergonomic hazards and the costs of eliminating those hazards are identified, the decision-maker must weigh the two and decide on the validity and effectiveness of intervening. This may also answer questions such as how much intervention is needed. The economic purpose of an intervention is to reduce overall opportunity costs. Cost minimization involves equalizing the marginal costs (MCs) before and after the intervention, as depicted in Figure 38.2. At I^*, MC of intervention (ΔCost of Intervention/ΔIntervention) is equal to MC of ergonomic hazard (ΔCosts due to Hazard/ΔIntervention).

Unlike CA, CBA is the primary tool for weighing costs of an intervention/program against its benefits (reductions in hazard exposure and associated injuries/illnesses), and it is often regarded as the gold standard of economic analysis for public policy in the United

TABLE 38.1 Costs of an Ergonomic Intervention

Factors	Metrics
	Direct Costs of Equipment
Purchase	Opportunity cost or market price
Fabrication	Market price
Replacement	Recycling cost for old equipment + installation costs
Maintenance	Time × wage + price of tools
Capital recovery factor	Market rate of interest + depreciation
	Direct costs of personnel
Training and consultancy	Payment to the trainer + time taken from work × wage rate
New hiring	Wages paid + benefits + search cost
	Indirect costs
Employee downtime	Time away from normal work and in reduced capacity × wage
Loss of production due to learning	Time away from work × wage + value of foregone output
Overhead costs	Utilities, facility maintenance, general administration, as calculated by accounting department as a percentage of direct costs

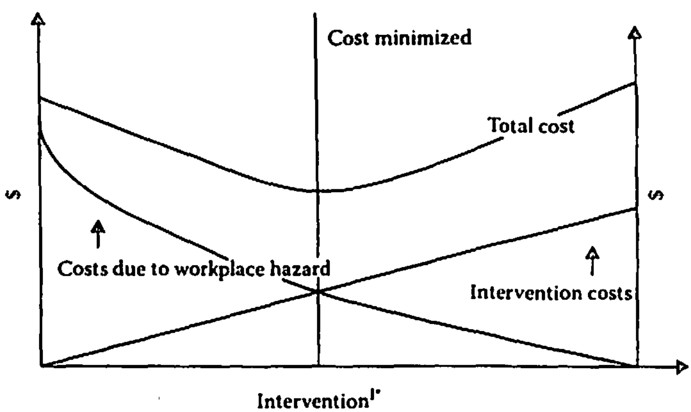


FIGURE 38.2 The economic factors involved in cost minimization CBA: ergonomic net benefits and intervention profitability.

States and Europe.* CBA is a form of economic evaluation that standardizes both costs and benefits in monetary terms (dollars) and provides a list of all costs and benefits accrued during a period. It is particularly helpful for deciding whether to implement a specific ergonomic program, deciding whether net benefits are positive, or for choosing the program option offering the highest ROI. If implementing a program results in a positive net benefit to society, then the program is efficient according to the Pareto improvement criterion.† This does not necessarily imply that the program may be beneficial from the company's

* See Dupuit (1952) and Rice (1966) for earlier utilization in public policy and health.

† An allocation is Pareto Efficient if there is no way to reallocate resources such that one individual is better off without making someone else worse off. However, if in principle the gainers can compensate the losers and still have a positive net gain, then the later situation is called Pareto Improvement over the former. See Stiglitz (1991).

perspective. Corporations may be interested in interventions that generate positive net benefits to the corporation. Incongruent cost and benefit timelines are adjusted, and *summary measures* for a CBA in monetary terms are typically presented as a single value, such as net present value (NPV), or as a ratio of benefit to cost:

$$\text{Net present value (NPV)} = \sum_{t=0}^{N} \frac{Benefit(B) - Cost(C)}{[1+r]^t},$$

where

t is the time period normally in years 0, 1,......N
N is the number of years being evaluated
r is the discount rate

An intervention project is feasible if NPV > 0. Similarly, one can calculate a benefit-cost ratio (BCR) as $\text{BCR} = \sum_{t=0}^{N} \frac{Benefit}{(1+r)^t} \Big/ \sum_{t=0}^{N} \frac{Cost}{(1+r)^t}$. A BCR > 1 implies that benefits will outweigh the cost. Discounting makes it possible to compare benefits and costs that occur at different times by adjusting their values according to the time preference corresponding to the chosen perspective. CDC recommends that a 3% social discount rate be used in analyses.

The conceptual and theoretical framework of CBA is derived from *welfare economics*, the branch of economics that attempts to maximize overall social welfare by examining the economic activities of individual members of society. At the societal level, CBA helps in deciding how to allocate the limited funding approved by federal, state, or local legislature. At the company or industry level, CBA enables decision-makers to assess how much money they will save or the benefits gained from implementing a safety or health program at the workplace. Unlike costs of illness as mentioned earlier, *cost* here stands solely for expenditures, tangible or not (such as labor, buildings, equipment, supplies, time, and effort) associated with a particular intervention. *Benefits*, on the other hand, are the monetary values of desirable consequences attached to that intervention. In the previous CA discussion, benefits may be equal to the costs of illness that will not be incurred as a result of intervention. Together with intervention costs, they reflect the changes in a company's profits or changes in individual and social welfare that result from implementing alternative programs. In comparison with benefits, costs of ergonomic interventions are easier to measure because cost factors are often fewer and the necessary accounting data are easily available. Table 38.1 earlier briefly lists some of these cost factors. These costs vary according to how early an ergonomic program is put into place (Alexander, 1999).

Benefits are generally classified as *direct*, *indirect*, and *intangible*. In general terms, direct benefits are the values of desirable health and non-health outcomes directly related to the implementation of proposed interventions that can be estimated by using market-based data (e.g., reduction in injuries or illnesses of the workers). Indirect benefits are the averted costs and savings resulting from the interventions but not related directly to them (such as reduction in absenteeism and presenteeism). Intangible benefits include the values of positive outcomes (e.g., reductions in pain and suffering), which cannot be estimated from market data.

Health factors: Changes in health outcomes are the direct or immediate result of an intervention. In most cases, improvements in health or safety conditions are the primary aim of the intervention. The majority of health-related outcomes considered in CBAs in public health fall into one of the following categories: decreased mortality, decreased morbidity, increased life expectancy, or reduced disability. In the context of ergonomic interventions, health-related outcomes will be reduced injuries and illnesses and reduced discomfort associated with them. For example, in the CBA of an intervention to reduce occupational lower-back pain in a nursing home, health factors might include reduced discomfort, reduced disability, reduced medical claims, and reduced WC claims. Identifying the relevant health factors for an economic evaluation often involves close consideration of available clinical, epidemiologic, and cost data.

Non-health factors: Such outcomes typically include elements such as productivity, staffing and salary issues, and product quality. Often, non-health outcomes may be significantly impacted by the health outcomes. When this occurs, they are attributed to the impact of an OSH intervention or program. For example, in the CBA of an intervention to reduce occupational lower-back pain in a nursing home, non-health factors would include (1) less whole or partial days lost due to sickness-related absence, (2) higher productivity and hence more efficient work force leading to lower time loss, (3) affected quality of care leading to patient well-being, and (4) less overtime and increased staffing needs.

A CBA should account for the values of these non-health outcomes to arrive at a correct measure of the economic benefits associated with an intervention.

Intangible factors: Intangible health outcomes (e.g., improved company reputation and improved quality of life) might be major considerations in implementing an intervention or health program and should be included if possible. However, companies typically do not include intangible costs and benefits.

The following steps are important in conducting a CBA*:

1. Define the problem.
2. Identify the prevention intervention to be evaluated.
3. Identify and classify effects of intervention (health and non-health) as costs or benefits.
4. Assign dollar values to the outcome of the preceding step.
5. Determine their present value, taking into account discount rate and inflation.
6. Determine and calculate the NPV or the BCR.
7. Evaluate the results for robustness with a sensitivity analysis on key parameters.†
8. Prepare the results for presentation.

* See Messonnier and Metzler (2003).

† See Appendix, part I.

Identifying the economic variables and classifying them as benefits or costs are the most important steps in conducting an economic analysis. Metrics to consider include health, non-health, and intangible factors. An analyst must include all metrics relevant to the study perspective while considering practical feasibility issues. Each metric is classified as either a benefit or a cost, according to the adopted viewpoint. For further examples of such analyses for ergonomic interventions, see Oxenburg (2005), Loisel et al. (2002), Hendrick (2003), and Lahiri (2005). We provide an example at the end of this chapter from Seeley and Marklin (2003).*

38.5.2 Cost-Effectiveness Analysis: Intervention Effectiveness and Choosing between Alternatives

Similar to CBA, CEA is a method used to compare effectiveness of alternative interventions in terms of their contributions toward a common economic outcome, such as better health or fewer injuries. CEA is used to compare the opportunity costs of alternative intervention strategies that produce a common health effect. CEA is preferred over CBA in situations where monetization of outcome effects is difficult and socially unacceptable (DeRango and Franzini 2003; Haddix et al. 2003; Drummond et al. 2005). Such effect measures are often expressed in physical or natural health units and include final outcomes (e.g., number of injuries prevented) or are given in terms of healthy outcome variables such as reduced absenteeism. The primary step is to measure the CE ratio for various alternative intervention scenarios (e.g., intervention A, intervention B, no intervention). The numerator consists of the net costs of a typical intervention (costs of intervention—costs of adverse health outcomes averted), and the denominator measures the net health outcome (health outcome post-intervention—health outcome pre-intervention). The ratio (net cost over net health outcome) will measure the effectiveness of the expenses made and will make a comparison between intervention programs easier. The smaller the ratio, the higher is the program's worth for the expenses. The various types of CE ratios are average cost-effectiveness ratio (ACER), marginal cost-effectiveness ratio (MCER), and incremental cost-effectiveness ratio (ICER). Suppose, to alleviate MSD problems among a cohort of workers, two interventions (A and B) are considered. Intervention A can be of large scale or small scale. The ACERs for the two intervention are $(C/E)_A$ and $(C/E)_B$:

$$\left(\frac{C}{E}\right)_A = \frac{(\text{intervention cost}_A - \text{injury/illness cost averted}_A)}{\text{total injuries/illnesses prevented}_A}$$

$$\left(\frac{C}{E}\right)_B = \frac{(\text{intervention cost}_B - \text{injury/illness cost averted}_B)}{\text{total injuries/illnesses prevented}_B}$$

The ACER provides useful information about the overall affordability of the intervention. If an intervention is cost-saving, then the corresponding ACER will be less than 0. In contrast to ACER, MCER provides information on the change in cost-effectiveness as

* See Appendix, part IV.

a result of expansion or contraction of an intervention and should be considered in conjunction with ACER. MCER is the ratio of additional costs to outcome obtained from one additional unit of intervention. For example, to solve back problems among desk workers, varying the number of workers being provided with back-supporting chairs will alter the cost-effectiveness ratio. The changes in net costs when divided by the extra reductions in lower-back pain incidences will give the MCER. Thus, by varying the degree of type *A* intervention, MCER is defined as

$$\left(\frac{\Delta C}{\Delta E}\right)_A = \frac{(\text{extra intervention cost}_A - \text{extra injury/illness cost averted}_A)}{\text{extra injuries/illnesses prevented}_A}.$$

Whether or not intervention *A* is CE depends on whether or not ACER is less than 0. However, to what degree intervention *A* is prudent depends on the value of MCER. Thus, MCER in conjunction with ACER can provide the decision-maker with the threshold value of intervention.

Prevention-effectiveness studies often require comparison between two alternative and mutually exclusive intervention strategies. Such studies benefit from the utility of the incremental cost-effectiveness ratio, or ICER:

$$\left(\frac{C}{E}\right)_{A-B} = \frac{(\text{additional intervention cost} - \text{additional injury/illness cost averted})}{\text{additional injuries/illnesses prevented}}$$

$$= \frac{[\{\text{intervention cost}_B - \text{intervention cost}_A\} - \{\text{injury/illness cost}_A - \text{injury/illness cost}_B\}]}{\text{injury/illness}_A - \text{injury/illness}_B}$$

A negative ICER implies that the alternative program is dominated by the program in question. For detailed discussion of intervention selection and ranking by ACER and ICER, consult Gift et al. (2003).

38.5.3 Cost Utility Analysis (CUA): Ranking Interventions with Regard to Nonmonetary Outcomes

CUA is a type of CEA in which benefits are expressed as utility preferences (measured in cardinal numbers) over numbers of life years saved, adjusted to account for loss of quality from morbidity of the health outcome or side effects from the intervention (Haddix et al. 2003). CUA is a unique form of economic evaluation that attempts to capture timing and duration of injuries, illnesses, and disability by comparing the utility associated with different health outcomes. Utility represents a person's preference for a specific outcome (or health state). CUA typically measures outcomes in quality-adjusted life years (QALYs) or disability-adjusted life years (DALYs). CUA is measured by the cost-utility ratio and can be expressed as the dollar value per QALY or DALY saved.

There are various steps involved in undertaking an economic analysis of ergonomic interventions. Knowing these steps will enable development of an economic evaluation study. Studies dealing with economic evaluation of OSH interventions are often criticized for the lack of understanding of the different steps of an economic analysis.

38.6 STEPS INVOLVED IN FRAMING AN ECONOMIC ANALYSIS

The first and the foremost step in conducting an economic analysis is framing of the study, which determines the research framework. Framing involves the following stages:

1. *Defining the problem*: The study problem must be identified at the outset of any analysis. A clearly stated problem defines the objective of the study. At this initial stage, consider what questions need to be answered and which aspects of the problem need to be explained.
2. *Defining the options*: The scope of the study and the variety of outcomes to be included are determined to a large extent by the nature of the programs under consideration.
3. *Defining the audience*: Understanding what information the audience needs and how the study results will be used are the major factors that must be considered at this stage.

   These questions will help to identify the audience (1) who will use the results of the analysis, (2) what information the audience might need, and (3) how the results will be used.
4. *Defining the perspective* (e.g., *company, industry, employee, societal)*: When using any perspective, only the benefits and costs relevant to that specific perspective should be considered. The CBA can be conducted from any of these perspectives, depending on the audience.
5. *Defining the time frame and analytic horizon*: The time frame and the analytic horizon are largely determined by the interventions under consideration. Time frame refers to the period through which intervention is undertaken while analytic horizon refers to the period over which the benefits and costs of intervention are distributed. The analytic horizon is usually longer than the time frame because the majority of interventions or treatments produce multiple health and non-health outcomes for periods far exceeding the durations of the interventions or treatments.
6. *Defining the discount rate, adjustment for inflation, and time preference*: *Discounting* makes it possible to compare benefits and costs that occur at different times by adjusting their values according to the time preference corresponding to the chosen perspective. CDC recommends that a 3% *social discount rate* be used in analyses.

The discount rate is one parameter that can be varied in a sensitivity analysis to test its impact on the results and to make the results of studies based on different discount rates comparable. At the company level, the cost of capital (borrowing/interest rate) is the appropriate discount rate.

Robustness of study results and treatment of uncertainty: Uncertainty may arise due to the presence of imperfect information and/or incomplete information. Intervention outcome is a result of interaction among many factors. In situations involving imperfect information, the statistical uncertainty that exists while mapping intervention to injury outcomes can be tackled by using range values around the defined confidence intervals. The economic evaluation analysis will then provide a range of possible outcomes to assist the decision-maker. However, when there is incomplete information on the costs and consequences of intervention, proxy measures and assumptions about certain parameters are necessitated. Univariate and multiway sensitivity and threshold analyses are undertaken in such situations to ascertain the robustness of outcome measures and their dependence on key parameters. Thus decision analysis can be defined as the use of analytic methods to inform complex decisions under conditions of uncertainty. The decision-maker calculates the expected outcome against probability-weighted outcome.* A detailed discussion of sensitivity analysis is beyond the scope of the current chapter. Ambitious readers should consult Briggs et al. (2006).

38.7 ERGONOMIC INTERVENTION APPROACHES

When a job is found to present high risk for WMSDs, then some type of ergonomic intervention is required. Industrial hygiene practice has adopted a general hierarchy of controls for implementing interventions. The hierarchy of controls suggests that the first choice for interventions is to use engineering controls, followed by administrative controls, and last by the use of personal protective equipment (PPE), if applicable. This hierarchy of control is based on the premise that the best approach for intervention is to use engineering controls to reduce or eliminate exposure to the job risk factors through automation, the use of mechanical aids, or ergonomic redesign of the workplace. Ergonomic redesign of the workplace typically includes modifying the workstation or tools to eliminate risk factors by modifying the job layout and procedures to reduce bending, twisting, horizontal extensions, heavy lifting, forceful exertions, and repetitive motions. Administrative controls, the second choice for interventions in the hierarchy of controls, typically aim to mitigate exposures to the risk factors by assigning additional workers, reducing exposure times, or attempting to hire specific workers or increasing training for workers. These approaches, however, do not always modify the risk factors themselves but rather serve to reduce the "dose" of physical exposure to each individual worker. Finally, the concept behind the use of PPE as an intervention is to try to protect the worker from exposure to specific risk factors. In industrial hygiene practice, this typically means using gloves, respirators, or body suits. For physical exposures, however, there is little PPE available for the risk factors associated with development of MSDs. Therefore, this is usually used only as a last resort. A more detailed discussion of ergonomic interventions can be found in the chapter on manual material handling (MMH), and a good source of information about ergonomic interventions for MMH jobs can be found in the NIOSH publication *Guidelines for Manual Material Handling* (NIOSH 2007).

* This is based on the expected utility theory by von Neumann, Morgenstern, Savage, and others. See Raiffa (1968) and Von Neumann, J. and O. Morgenstern (1953).

Some of the economic considerations of interest in choosing an ergonomic intervention include the costs and benefits associated with factors such as (1) obtaining and implementing the intervention, (2) conducting training classes, (3) changes in personnel levels, (4) changes in productivity, and (5) changes in product quality.

38.8 SUMMARY OF COST-BENEFIT MODELING TOOLS

A number of tools have recently been created to assist in the development of cost-benefit models to quantify the effects of implementing workplace interventions, often of an ergonomic nature. The tools vary greatly in cost, sophistication, focus, and input information required. The tools and associated software, if available, range in price from free to several hundred dollars each. Some of the tools are relatively simple, utilizing default values and requiring limited user input, but others are fairly complicated, with specific geographic location and injury default data and requiring more user-supplied data. Several models focus on changes to productivity as the basis for analysis, whereas other tools focus on the potential savings from injury or illness avoidance. The examples provided are not intended to be all-inclusive but representative of the types of tools available.

The "$afety Pays" program of the U.S. Department of Labor Occupational Safety and Health Administration OSHA (2009) is a free, interactive, Internet-based system which assists users in estimating the cost of occupational injuries and illnesses and their impact on the profitability of a company. The program uses the company's profit margin (real or default value), the cost of an occupational injury or illness (actual or national average), and an indirect cost multiplier to compute an estimated amount of sales a company would have to produce to cover the associated costs of the injury or illness. The program is also available in a plain text version.

The "productivity assessment tool" described by Oxenburgh and Marlow (2005) focuses on the costs and benefits associated with the employment of workers, primarily through measures of their productivity. This tool is often used to measure the increase in cost-effectiveness of employees after an intervention by contrasting "before" and "after" findings. The primary measure of this tool is productivity, defined as the ratio of time paid for by the employer and the time the employee spends actively working, coined "the productive hours." This measure is typically taken for a 1 year period. Nonproductive hours paid by the employer include workplace absences for injuries, illnesses, vacations, holidays, training, etc. Shorter time periods are addressed by considering "reduced productivity" from an ideal or optimal condition. This tool, however, does not directly address either the quantity or quality of the output during productive time. Nor does it address presenteeism, in which an individual may be at work but not working up to expectations because of illness, distraction, or motivation. In general, there is no consideration of injury or illness costs with this tool.

The "return on health, safety, and environmental investments" (ROHSEI) tool and supporting software tool set described by Linhard (2005) was developed to provide occupational health, safety, and environmental staff a comprehensive look at investment decisions, including the implementation of ergonomic interventions. The ROHSEI system uses a four-step process to build a business case for each investment: (1) define the focus of the investment opportunity, (2) identify alternative solutions, (3) consider direct and hidden benefits, and (4) make recommendations. This system was designed for use by a team of analysts and may be too complicated for an individual to use effectively. This tool is also the most expensive of those presented.

The net-cost model reported by Lahiri et al. (2005) was developed to estimate the net economic costs of investments in ergonomic intervention to address LBP from a company or facility perspective. The model consists of a series of 23 equations that assist the user in determining the direct equipment costs, avoided medical care costs, lost productivity due to injury, improved productivity due to the intervention, and net economic cost of the intervention. Some of the variables used in the analysis, such as capital recovery factor, rate of return on private capital, and depreciation rate, may not be readily available to the OSH staff conducting the analysis.

However, it is often the case as Boff and Rouse (1997) recognizes that, in ergonomics and human factors arena, much of the traditional ROI data are simply not available. In the absence of detailed data and with lack of understanding of the available tools, economic analysis using those tools will largely affect the results obtained. It is always better to follow a simplified approach of CBA relying on the better understanding of the scope of the study which includes identifying stakeholders, defining benefits and costs, and evaluating alternative work practices.

38.9 CONCLUSIONS

Ergonomics and economics are in alignment: safe and productive work likely will cost less in the long run and increase profits for the company. Although the primary focus of occupational ergonomics is the design of safe and productive jobs, if the costs to implement ergonomic interventions are too great or the payback period for the investment is too long, then it may be difficult to convince management to invest in the most effective solutions. CBA can be an effective tool for making decisions about which intervention to implement when a high-risk job has been identified. A significant ROI and/or a short payback period can be effective in obtaining management approval for implementing ergonomic interventions. A conservative estimate is often preferred to ensure that future business case estimates are believable and achievable. To the extent feasible, assessments of costs and benefit should include factors associated with prevention of MSDs, work productivity, and quality. Oftentimes, the best benefit of an ergonomic intervention will be an increase in productivity rather than a savings due to reducing risk of MSDs. Also, a company may have high exposures to risk factors for MSDs but not have any significant reports of MSD injuries, for a number of reasons. There may be some incentive program for not reporting injuries, injuries may not be recorded as work-related, or workers may visit their own primary physician rather than the corporate doctor, so cases may be overlooked. In these instances, cost avoidance may be an important factor to consider when building a business case for an ergonomic intervention.

38.A APPENDIX A

38.A.1 General Health Valuation Methods

38.A.1.1 Cost-of-Illness Method

The *cost-of-illness (COI)* method is used to estimate the direct and indirect costs of an intervention. This method is based on the *human capital approach* and is discussed in detail in the CA module. *Intangible costs* of illness and the benefits of averted illness are estimated by means of *nonmarket valuation* methods.

38.A.1.2 Nonmarket Valuation Methods

The choices people make in the marketplace (i.e., their behaviors) result from their valuations of the goods they buy and the prices they are willing and able to pay. If a market exists, we can comfortably use what consumers are willing to pay as an estimate of how much they value the good. Therefore, existence of a market is relevant in this search. However, because the majority of health outcomes (e.g., health risks) do not have markets, valuing them presents analytical challenges.

Economists have developed theoretically sound and intuitively appealing ways of estimating the value of nonmarket goods. These methods and procedures are based on generally accepted economic theories and are broadly referred to as *nonmarket valuation* methods. Until recently, these methods were applied primarily to the valuation of environmental and natural resources. They are now a relevant and necessary part of contemporary safety and health research. In general, two main valuation methods are employed: *revealed preference* method (RPM) and *stated preference* method.

38.A.1.2.1 Revealed Preference Method *Hedonic pricing* and *averting behavior* are the two main types of *RPMs* used in health economics. By the use of these indirect methods, a person's valuation of a safety or health outcome is observed through actions in markets that already exist. This behavior in the market is used to make inferences about the person's valuation of the related safety or health outcome.

38.A.1.2.2 Hedonic Pricing (Wage) Most goods come in bundles. Each bundle is made up of various components (or characteristics) that are not separable but that might be presented in different ways and sold altogether at one price. Each of these components (or characteristics) might confer a different benefit on the buyer. Therefore, a buyer might pay more to have each additional characteristic or to have more of any one particular characteristic.

The *hedonic* model is based on this principle. The prices that consumers pay or receive are reflections of the different components of the goods in question. For example, the wage rate that underground miners receive is a price for their labor that is determined on the labor market. This price depends on characteristics of the miner that can be objectively measured (such as number of years on the job [experience] and educational level).

On the labor market (which is assumed to be competitive), employers are willing and able to pay more for each characteristic, in both quality (type) and quantity (amount).

A functional relationship therefore exists between the wage and all the measurable characteristics. This relationship can be expressed as follows:

$$W = f(q, e, ex, a, g),$$

where
W is the wage
q is the qualification
e is the education
ex is the experience
a is the age
g is the gender

If data were available, all of these characteristics and outcomes could be subjected to a rigorous empirical analysis (such as a regression analysis) to obtain how much more employers pay to have a unit increase in each of the characteristics, with controls for other factors. This amount is the implicit price received by the worker or paid by the employers for a unit of that particular characteristic. It is used to represent the employer's or worker's value of that characteristic, as determined by the existing conditions in the labor market.

38.A.1.2.3 Averting Behavior The value of a small change in safety and health status can be measured by the amount of money a person is willing and able to spend on some controlling or preventive device or defensive (averting) action. This amount of money may be used to represent the person's valuation of safety against a perceived risk.

Some examples of preventive devices on which persons might spend money to mitigate perceived risk include safety helmets, smoke detectors, seatbelts on tractors, larger cars, and non-mandated PPE.

38.A.1.2.4 Stated Preference Method This direct method uses primary surveys that ask individuals to place values on an intervention to attain a level of health outcome in question. The technique is generally known as the *contingent valuation method (CVM).* The major advantage of the *CVM* over the *RPM* is that it estimates both *tangible* and *intangible values*, thereby providing a better estimate of the true value of the intervention or action.

Like any other economic evaluation, proper framing of a CBA is of major importance. To assess the effectiveness of an ergonomic intervention, one needs to understand and emphasize the consequences that are only specifically attributed to the intervention. An intervention to reduce stress may have different consequences on the study population, depending on whether or not the economy is in recession or not. Understanding these macro-level factors and similar other confounding factors is of primary importance. Equally important is the time period through which the costs are incurred and benefits are accrued. Intervention investments may be limited to a few years in the beginning, but the benefits may accrue over time. It is important to translate these long-term costs and benefits into their current monetary values for the decision-maker. Although CBA is used more often in other fields of decision-making, in health care research, it is often replaced by CEA and CUA.

38.B APPENDIX B

Example of economic analyses of ergonomic interventions: Business case for implementing two ergonomic interventions at an electric power utility (Seeley and Marklin 2003) is provided here. Ergonomic analysis of line workers (n = 370) in a large Midwestern U.S. electric utility company revealed 32 common line worker tasks that were rated at medium to high magnitude of risk factors MSDs. A university ergonomics team rated the potential interventions and came up with a list of 9 low cost–high value interventions out of which 2 were believed to have a significant improvement on occupational health of workers.

Jobs needing ergonomic intervention: (1) manual tool for applying compression connectors to wire; (2) manual wire cutting.

Ergonomic interventions: (1) battery-operated tool for pressing connector and (2) battery-operated tool for cutting wire.

Figures 38.A.1 and 38.A.2 depict the battery-operated tools. The risk factors with the manual tools are the source of the cost of the pre-intervention work practices and are the

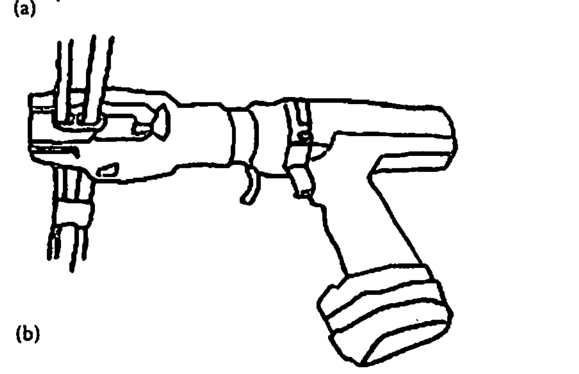


FIGURE 38.A.1 Intervention 1: a compression connector crimped with a manual operation (a) and battery-operated press (b). (EPRI 2001.)

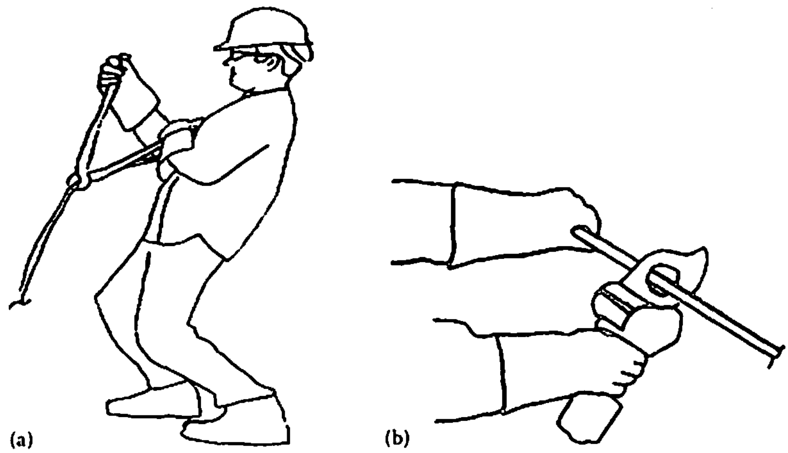


FIGURE 38.A.2 Intervention 2: A line worker cutting a large diameter wire with a manual cutter (a) and a battery-operated cutter (b). (EPRI 2001.)

benefits that are gained when manual tools are replaced with the battery-operated ones. For CA of pre-intervention work practices (manual tools), the analyst has to monetize the health problems and associated work place costs and define them as costs. While doing CBA for the intervention (battery-operated tools), these cost estimates will enter into the benefit side of the equation as avoided costs (Tables 38.A.1 through 38.A.6).

TABLE 38.A.1 Risk Factors of MSDs from Making Compression Connections with the Manual Press and Improvements with the Battery-Operated Press

Risk Factor	Manual Press Risks	Improvement with Battery-Operated Tool
Amount of handle force required too empress a 1/0-12 who pair is approximately 311 N at the outer location of the manual press	Only 1% capable of the general population has the peak forces to make this connection	Nearly all workers capable
High shoulder force exertions working from a pole	Peak shoulder muscle EMG using the manual press was over 50% MVC (maximal voluntary contraction)	Reduced from over 50% MVC to 30% MVC (40% relative reduction)
High shoulder force exertions working from a bucket	Peak EMG 45% MVC	Reduced to less than 10% MVC (over 80% relative reduction)
Peak forces of flexor muscles in forearm from working on pole	Peak EMG of 90% MVC	Peak decreased from 90% MVC to 60% MVC (a 33% relative reduction)
Peak forces of flexor muscles in forearm from working in bucket	Peak EMG of 100% MVC	From 100% MVC to 60% MVC (a 40% relative decrease)
Jarring action of manual compression tool	Not measured, but substantial	Eliminated 100% virtually all workers capable
Twisted and awkward trunk postures		Improved posture from the bucket

Source: Reprinted from Seeley, P.A. and Marklin, R.W., *Appl. Ergonomics*, 34, 429, 2003.

TABLE 38.A.2 Risk Factors of MSDs from Cutting Wire with Manual Tools and Improvements with the Battery-Operated Cutter

Risk Factor	Current Practice Risks	Improvement with Battery-Operated Cutter
High upper extremity force exertions to close cutter handles	Operating a cutter is similar to operating a manual press	Substantially reduced
Forceful lowering of arms (shoulder abduction)	High forces exerted by the upper extremity and shoulders although not measured	Substantially reduced with a finger pull on the trigger
Arms raised above shoulder level (shoulder abduction)		Substantially reduced
Jarring action from quick drop in force when wire is cut		Eliminated
Repetitive upper extremity exertions using the rather cutter		Eliminated
Twisted and awkward trunk postures from bucket		Improved posture

Source: Reprinted from Seeley, P.A. and Marklin, R.W., *Appl. Ergonomics*, 34, 429, 2003.

TABLE 38.A.3 All Reported MSDs (January 1999–July 2001) of Line Workers (n = 370) at the Utility by Body Part and Progression of Reporting

	Progression by Reporting				
Body Part or Injury Type	Early (First Aid or First Time Medical Treatment)	Mid (OSHA Recordable Injuries)	Late (Occupational Illness, Inflammation, RD, and LWDs)	Total	% Reported Late
Non-repetitive	11	5	1	17	3
Wrist	5	1	1	7	14
Elbow	4	8	2	14	14
Shoulder	6	6	7	19	37
Upper arm	0	0	1	1	100
Forearm	1	1	1	3	33
Buck	25	12	20	57	35
Leg	1	0	0	1	0
Knee	15	8	2	25	8
Neck	0	0	3	3	100
Inflammation	1	2	3	6	50
Carpal tunnel syndrome	0	2	3	5	60
Other occupational illness	0	1	1	2	50
Multiple body parts	3	3	2	7	17
Totals	72	48	47	167	28

Source: Reprinted from Seeley, P.A. and Marklin, R.W., *Appl. Ergonomics*, 34, 429, 2003.

The bold-faced numbers reflected the body parts with high number of incidences. Early and mid injuries resulted in no LWDs or RD days; late injuries resulted in RD days or LWDs or were relatively severe, such as those requiring surgery. A thorough review of the table shows that approximately 73% of injuries were not reported. Also, it was found that costs of treating injuries are much lower at the early stage than at the later stage. Average costs for injury treatment were calculated based on only reported injury data and are given in Table 38.A.4.

TABLE 38.A.4 Utility's Medical and Workers' Compensation Costs for 47 MSD Injuries That Resulted in LWDs or RD Days (January 1999–July 2001)

Type of Injury	Total Medical Costs, Indemnity, Reimbursements for Drugs, Parking, Transportation	Annualized	Annualized per Employee $N = 370$
Upper extremity injuries	$179,296	$71,718	$194
Neck injuries	$160,573	$64,229	$174
Knee injuries	$46,207	$18,522	$50
Back injuries	$92,429	$36,971	$99
Totals	$478,605	$191,440	$317

Source: Reprinted from Seeley, P.A. and Marklin, R.W., *Appl. Ergonomics*, 34, 429, 2003.

The costs of replacing 43 of the 47 workers who incurred injuries resulting in restricted or lost work days are shown in Table 38.A.5. Based on this, the annualized cost per line worker for replacing skilled injured workers categorized by upper extremity and back are given in Table 38.A.6.

TABLE 38.A.5 Restricted Duty Days and Lost Workdays of MSDs Requiring Full-Time Replacement Workers Categorized by All Body Parts and Injury Types

Body Part/ Injury	# of RD Cases	# of RD Days	# of LWD Cases	# of LW Days	Totals RD/LW Days Missed	Replacement Worker Costs Totals (Skilled Worker at $36/h)	Annualized per Line Worker ($n = 370$)
Shoulder	7	185			185	$56,448	$61
Back	17	407	3	90	497	$143,136	$155
Knee	1	90	1	43	133	$51,552	$56
Elbow	2	2			2	$576	$1
Inflammation	3	60			60	$17,280	$19
Carpal tunnel syndrome	1	14	2	41	55	$15,840	$17
Occupational illness	1	56			56	$16,128	$17
Multiple body parts	1	20	1	11	31	$5,760	$6
Wrist	1	3			3	$864	$1
Upper arm	1	2			2	$576	$1
Forearm	1	46			46	$0	$0
Totals	36	885	7	185	1070	$308,160	334

Source: Reprinted from Seeley, P.A. and Marklin, R.W., *Appl. Ergonomics*, 34, 429, 2003.

Notes: Total number of RD and LWD cases with full data was 43; four of the 47 did not have full data (January 1999–July 2001).

TABLE 38.A.6 Average Restricted Duty Days and Lost Workdays of MSDs Requiring Full-Time Replacement Workers Categorized by Upper Extremity and Back (January 1999–July 2001)

Body Part Injury	# of RD Cases	# of RD Days	# of LWD Cases	# of LW Days	Totals RD/ LW Days Missed	Replacement Worker Costs Totals (Skilled Worker at $36/h)	Annualized per Line Worker ($n = 370$)
Upper extremity and neck only	18	388	3	52	440	$126,720	$137
Back only	17	407	3	90	497	$143,136	$155

The following data from the utility during the January 1999–July 2001 period were reviewed:

1. Medical and workers' compensation costs for 47 cases of MSDs that resulted in time off work, either restricted duty (RD) days or LWDs.
2. The total number of MSDs (n = 167) experienced by all the line workers at the utility not resulting in time off work.
3. Training and productivity costs for apprentice line workers. This is the replacement cost for skilled line workers experiencing permanent time off work.
4. Replacement costs for skilled line workers temporarily off work due to injury/illness.
5. Personnel records for line workers leaving their job. This helps in estimating turnover costs.
6. Personal information on hourly wages and benefits by job classification.

Estimating the costs associated with work injuries: Data for the following were obtained to calculate work injury costs:

1. Permanent partial or total disability costs
2. Lost time (hourly rate multiplied by number of hours missed per occurrence); includes operation downtime due to injury
3. Medical costs: doctors, tests, hospital, physical therapy, chiropractic care, company medical evaluations
4. Time spent discussing the injury or illness with workers, supervisors, health care professionals
5. Sick days' costs for injuries not reported as work-related
6. Clerical time handling claims and case investigation

38.B.1 Cost-Benefit Analysis

Seeley and Marklin (2003) assume that the intervention will reduce injuries and illnesses by 50%. This is a critical assumption about the most important parameter in the analysis. Usually, such parameter estimates rely on a suitable Bayesian prior where the base value comes from previous studies and reliable sources. In general terms, one can assume this as flexible and vary the value to do a sensitivity analysis. For example, we take the value as ϕ, where $\phi \in [0,1]$. $\phi = 0$ implies that the interventions are 100% effective in controlling injuries.

For medical and workers' compensation cost prior and post-intervention, we follow Seeley and Marklin (2003) and consider only those injuries that are restricted to upper extremity and neck region. We also follow them and assume that medical costs increase by 8% annually. Table 38.A.7 gives the costs pre- and post-intervention on an annual basis.

TABLE 38.A.7 Annual Cost Pre and Post Intervention

Factor	Manual Tools	Battery-Operated Tools	Difference = Avoided Costs = Benefits
Medical and WC	\$146,822	\$(146,822 × ϕ)	\$146,822 (1 − ϕ)
Replacement workers	\$50,688	\$(50,688 × ϕ)	\$50,688 (1 − ϕ)
Retraining costs	\$91,000	\$(91,000 × ϕ)	\$91,000 (1 − ϕ)
Late injury reporting	\$80,000	\$(80,000 × ϕ)	\$80,000 (1 − ϕ)
Total			\$368,510 (1 − ϕ)

ϕ = 0.0	ϕ = 0.1	ϕ = 0.2	ϕ = 0.3	ϕ = 0.4	ϕ = 0.5	ϕ = 0.6	ϕ = 0.7	ϕ = 0.8	ϕ = 0.9	ϕ = 1.0
308510.8	271659.7	234808.6	197957.5	161106.5	124255.4	87404.3	50553.23	13702.15	-23148.9	-60000

Annual costs to obtain equipment: Total costs to provide tools for 100 crews × \$3,000 per crew (\$2,000/battery-operated press; \$1,000/battery-operated cutter) divided by 5 years equals \$300,000/5 = \$60,000/year.

Net annualized benefits at the end of year 1 = \$[368,510 (1 − ϕ)−60,000]. Following are the values for respective ϕ values. It is evident that the net benefits will be positive if the interventions are 20% effective. Similarly, the benefit-cost ratio is greater than 1, when $\phi \leq 0.84$.

Payback period: (\$60,000/\$368,510 (1 − ϕ)) × 12 months. For ϕ = 0.5, the payback period becomes 3.9 months.

REFERENCES

Alchian, A. and H. Demsetz (1972). Production, information costs, and economic organization. *Am Econ Rev* 62:777–795.

Alexander, D. (1999). *The Cost Justification Process.* Auburn, AL, Auburn Engineers, Inc.

Baker, L. C. and A. B. Krueger (1995). Medical costs in workers' compensation insurance. *J Health Econ* 14(5):531–549.

Boff, K. R. and W. B. Rouse (1997). Assessing cost/benefits of human factors. In: *Handbook of Human Factors and Ergonomics,* 2nd Edn. New York, Gavriel Salvendy, Wiley, pp. 1617–1633.

Briggs, A., K. Claxton et al. (2006). *Decision Modelling for Health Economic Evaluation.* New York, Oxford University Press.

Cutler, D. M. (1994). A guide to health care reform. *J Econ Perspect* 8(3):13–29.

DeRango, K. and L. Franzini (2003). Economic evaluations of workplace health interventions: Theory and literature review. In J. C. Quick and L. E. Tetrick, (eds). *Handbook of Occupational Health Psychology.* American Psychological Association, Washington, DC.

Drummond, M., M. Sculpher et al. (2005). *Methods for the Economic Evaluation of Health Care Programmes.* Oxford, U.K., Oxford University Press.

Dupuit, J. (1952). On the measurement of utility of public works. *International Economic Papers* 2:83–110.

Electric Power Research Institute (EPRI) (2001). Final report for ergonomics handbook for the electric power industry: Overhead distribution line workers interventions. EPRI Report Number 1005199, EPRI, Palo Alto, CA.

Gift, T. L., A. Haddix, and P. Corso (2003). Cost-effectiveness analysis. In: A. Haddix et al., eds. *Prevention Effectiveness: A Guide to Decision Analysis and Economic Evaluation,* 2nd Edn. Oxford, U.K., Oxford University Press, p. 156.

Goetzel, R. Z., S. R. Long, R. J. Ozminkowski, K. Hawkins, S. Wang, and W. Lynch (2004). Health, absence, disability, and presenteeism cost estimates of certain physical and mental health conditions affecting U.S. employers. *J Occup Environ Med* 46(4):398–412.

Haddix, A., P. Corso, and R. Gorsky (2003). Costs. In: A. Haddix et al., eds. *Prevention Effectiveness: A Guide to Decision Analysis and Economic Evaluation*, 2nd Edn. Oxford, U.K., Oxford University Press, p. 53.

Hendrick, H. W. (2003). Determining the cost-benefit of ergonomics projects and factors that lead to their success. *Appl. Ergonomics* 34:419–427.

Humphrey, T. M. (1997). Algebraic production functions and their uses before Cobb-Douglas. *Econ Q* 83(1):51–83.

Lahiri, S., J. Gold, and C. Levenstein (2005). Net-cost model for workplace interventions. *J Safety Res* 36:241–255.

Leigh, J. P., S. Markowitz et al. (2004). *Costs of Occupational Injuries and Illnesses*. Ann Arbor, MI, The University of Michigan Press.

Linhard, J. B. (2005). Understanding the return on health, safety and environmental investments. *J Safety Res* 36:257–260.

Loisel, P., J. Lemaire, and S. Poitras et al. (2002). Cost-benefit and cost-effectiveness analysis of a disability prevention model for back pain management: A six year follow up study. *Occup Environ Med* 59:807–815.

Messonnier, M. and M. Metzler (2003). Cost-benefit analysis. In: A. Haddix et al., eds. *Prevention Effectiveness: A Guide to Decision Analysis and Economic Evaluation*, 2nd Edn. Oxford, U.K., Oxford University Press, p. 127.

NIOSH (1997). *Musculoskeletal Disorders and Workplace Factors: A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back*. Cincinnati, OH, U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

NIOSH (2007). *Ergonomic Guidelines for Manual Material Handling*. Cincinnati, OH, Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2007-13 1 [http://www.cdc.gov/niosh/docs/2007-13 111].

NRC and IOM (2001). *Musculoskeletal Disorders and the Workplace Low Back and Upper Extremities*. Washington, DC, National Academy Press.

OSHA (2009). "$afety Pays" Program [www.osha.gov/dcsp/smallbusiness/safetypays/index.html]. Washington, DC, U.S. Department of Labor, Occupational Safety and Health Administration. Accessed December 8, 2009.

Oxenburgh, M. and P. Marlow (2005). The productivity assessment tool: Computer-based cost benefit analysis model for the economic assessment of occupational health and safety interventions in the workplace. *J Safety Res* 36:209–214.

Pauly, M. V., S. Nicholson et al. (2008). Valuing reductions in on-the-job illness: Presenteeism from managerial and economic perspectives. *Health Economics* 17(4):469–485.

Raiffa, H. (1968). *Decision Analysis: Introductory Lectures on Choices under Uncertainty*. Reading, MA, Addison-Wesley.

Rice, D. (1966). *Estimating the Cost of Illness*. Washington DC: Department of Health, Education and Welfare, Public Health Service, Health Economic Series 6.

Rice, D. P., E. J. MacKenzie et al. (1989). *Cost of Injury in the United States: A Report to Congress*. San Francisco, CA, Institute of Health and Aging, University of California Injury Prevention Center, Johns Hopkins University.

Samuelson, P. A. and W. D. Nordhaus (2001). *Macroeconomics*. Boston, MA, McGraw-Hill/Irwin.

Seabury, S. A., D. Lakdawalla, R. T. Reville (2005). *The Economics of Integrating Injury and Illness Prevention and Health Promotion Programs*. RAND Institute for Civil Justice working paper series, WR-243 = ICJ. Santa Monica, CA, RAND, Institute for Civil Justice.

Seeley, P. A. and R. W. Marklin (2003). Business case for implementing two ergonomic interventions at an electric power utility. *Appl Ergonomics* 34:429.

Stiglitz, J. E. (1991). *The Invisible Hand and Modern Welfare Economics in Information, Strategy and Public Policy*. Oxford and Cambridge, MA, Blackwell, pp. 12–50.

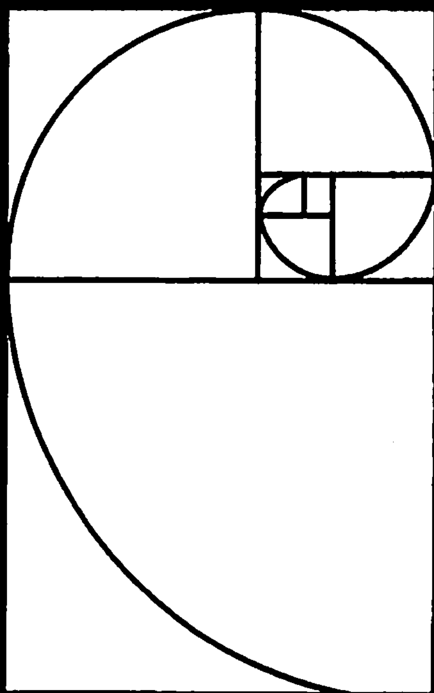
U.S. Chamber of Commerce (1993). Table 4. Employee Benefits, 1992. Washington, DC, U.S. Chamber of Commerce.

Von Neumann, J. and O. Morgenstern (1953). *Theory of Games and Economic Behavior*. Princeton, NJ, Princeton University Press.

Occupational Ergonomics

Theory and Applications

Second Edition



edited by

Amit Bhattacharya
James D. McGlothlin

CRC Press
Taylor & Francis Group

Occupational Ergonomics

Theory and Applications

Second Edition

edited by
Amit Bhattacharya
University of Cincinnati Medical College
Cincinnati, Ohio
Co-Founder, OsteoDynamics, Inc.
Cincinnati, Ohio

James D. McGlothlin
Purdue University
West Lafayette, Indiana

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an informa business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed in the United States of America on acid-free paper
Version Date: 20120112

International Standard Book Number: 978-1-4398-1934-0 (Hardback)

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

In the fifteen years since the publication of **Occupational Ergonomics: Theory and Applications**, significant advances have been made in this field. These advances include the impact of aging and obesity on workplace, the role of ergonomics in promoting healthy workplaces and healthy life styles, the role of ergonomic science in the design of consumer products, and much more. The caliber of information and the simple, practical ergonomics solutions in the second edition of this groundbreaking resource, though, haven't changed.

See What's New in the Second Edition:

- Enhanced coverage of ergonomics in the international arena
- Emerging topics such as healthcare ergonomics and economics of ergonomics
- Coverage of disability management and psychosocial rehabilitation aspects of workplace and its ergonomics implication
- Current ergonomics solutions from "research to practice"
- Synergy of healthy workplaces with healthy lifestyles
- Impact of physical agents on worker health/safety and its control
- Additional problems with solutions in the appendix

The book covers the fundamentals of ergonomics and the practical application of those fundamentals in solving ergonomic problems. The scope is such that it can be used as a reference for graduate students in the health sciences, engineering, technology, and business as well as professional practitioners of these disciplines. Also, it can be used as a senior-level undergraduate textbook, with solved problems, case studies, and exercises included in several chapters. The book blends medical and engineering applications to solve musculoskeletal, safety, and health problems in a variety of traditional and emerging industries ranging from the office to the operating room to operations engineering.

CRC Press
Taylor & Francis Group
an informa business
www.taylorandfrancisgroup.com

6000 Broken Sound Parkway, NW
Suite 300, Boca Raton, FL 33487
711 Third Avenue
New York, NY 10017
2 Park Square, Milton Park
Abingdon, Oxon OX14 4RN, UK

K11020
ISBN: 978-1-4398-1934-0
90000
9 781439 819340
www.crcpress.com